Monograph:
Miraldo, M. (2007) Reference pricing versus co-payment in the pharmaceutical industry: firms' pricing strategies. Working Paper. CHE Research Paper . Centre for Health Economics, University of York , York, UK.

THE UNIVERSITY of York

CHE
Centre For Health Economics

Reference Pricing Versus Co-Payment in the Pharmaceutical Industry: Firms' Pricing Strategies

CHE Research Paper 27

Reference Pricing Versus Co-Payment in the Pharmaceutical Industry: Firms' Pricing Strategies

Marisa Miraldo

Centre for Health Economics
University of York
York YO10 5DD
Email: mafm100@york.ac.uk

April 2007

Background

CHE Discussion Papers (DPs) began publication in 1983 as a means of making current research material more widely available to health economists and other potential users. So as to speed up the dissemination process, papers were originally published by CHE and distributed by post to a worldwide readership.

The new CHE Research Paper series takes over that function and provides access to current research output via web-based publication, although hard copy will continue to be available (but subject to charge).

Acknowledgements

This article has been strongly improved with comments by Hugh Gravelle, Kurt Brekke, Matteo Galizzi, Michael Kuhn, Pau Olivela and Peter C. Smith to whom I am grateful. This paper was written with financial support from the *Sub-Programa Ciência e Tecnologia do 2o Quadro Comunitário de Apoiodo Ministério da Ciência e Tecnologia* and *Fundação Calouste Gulbenkian,* both in Portugal.

Centre for Health Economics
Alcuin College
University of York
York, UK
www.york.ac.uk/inst/che

Abstract

Within a horizontally differentiation model and allowing for heterogeneous qualities, we analyze the effects of reference pricing reimbursement on firms' pricing strategies. With this analysis we find inherent incentives for firms' pricing behaviour, and consequently we shed some light on time consistency of such policy. The analysis encompasses different reference price rules. Results show that if drugs have equal quality, reference pricing may lead to higher prices. With quality differentiation both the minimum and linear policies unambiguously lead to higher prices.

1 Introduction

Expenditure in pharmaceuticals is one of the major factors behind the growth of the total expenditure on health care in OECD countries. Indeed, in most countries it represents a share between 10 and 20% of total costs (Mossialos and Le Grand 2002), being this weight bigger in low income countries. Furthermore, during the 1990s the rate of growth of expenditure in pharmaceuticals, both total and per capita, was higher than both the rate of growth of inflation and the rate of growth of total health care costs (Mossialos 2002). Since in most countries these expenses are borne publicly (Mossialos 2002) they have been one of the main targets of public policy. Namely, through the launch of regulation policies, competition incentives, reimbursement schemes, antitrust policies, among others. Despite being targeted to affect different sides of the market, the goal of these policies tends to be unique: the control of (public) pharmaceutical expenditure policies either through quantity control (demand side measures) or through price control (supply side measures). In publicly funded systems, drug costs are borne either through public insurance schemes (e.g. Belgium) or through direct discount on the market price. Traditionally, consumers have always paid a proportion of the total price – co-payment - while the remaining was borne by the third party payer. This partial accountability for drug costs is on the basis of moral hazard problems, by which, there exists (non optimal) over consumption of prescription drugs. Associated with the moral hazard problem, this reimbursement tool is also believed to be quite limited in providing competition incentives as well as exposes consumers to risks by limiting the risk-spreading feature of health insurance. These drawbacks, namely the first two, lead policy makers either to abandon or complement this reimbursement system. It has been in this context that policies such as reimbursement ceilings, special schemes for the reimbursement of orphan drugs and reference pricing policies were born.

This paper focus on the analysis of the impact of reference pricing policy on firms pricing strategies by considering two different reference pricing rules and a scenario where drugs quality might differ.

Reference Pricing (RP) is a regulatory mechanism consisting of clustering drugs according to some equivalence criteria (chemical, pharmacological or therapeutic) and defining a reference price for each cluster. The third party payer, then, will just reimburse not more than that price for each drug on that cluster. If a consumer buys a drug with price lower or equal to the reference price of that cluster, then the co-payment he faces is null. Otherwise, if the drug bought is priced higher than the reference price, the consumer will bear, fully or partly, the difference between the reference price and the drug price.

Even though its formulation varies from country to country, reference pricing is generally seen as an efficient mechanism in cutting drug prices by encouraging self restraint, in controlling relative demand of highly priced drugs and in encouraging the appropriate use of drugs. Based on this premises, third party payer's pharmaceutical expenditure would be controlled.

However, the effectiveness of this mechanism ultimately depends on its ability in enhancing competition in the drug market and on the promotion of financial responsibility by consumers and pharmaceutical firms. Indeed, competition enhancement has been often pointed as the rationale for the implementation of such policy (Lopez-Casasnovas and Jonsson 2001; Ma 1994). Based on the premise that competition in the pharmaceutical market is insufficient due to patients and prescribers weak information and/or insensitivity to prices, reference pricing is believed to increase demand sensitivity to prices and hence promote competition. Indeed, by making patients liable for the extra drug cost above reference pricing, the latter creates incentives for the substitution between close substitutes and consequently enhances price competition. Nevertheless, being a demand side measure, firms behavior is only influenced indirectly via demand effects. Indeed, under this policy, firms can freely set their prices. Moreover, despite the heterogeneity of the reference pricing rules in the different countries, conceptually they share the same feature of being based on firms pricing strategies. On the top of the non optimality issues that may arise with this formulation, one should add the incentives that profit maximizing rational firms to reformulate their pricing strategies in order to achieve higher profits. In fact, by accounting for the fact that each period the reference pricing level will be calculated having as basis observed prices in the previous period, firms will have an incentive to price at higher levels than they would in the absence of reference pricing. If this hypothesis is verified then the reference pricing implementation rationale of competition enhancement is seriously at danger. Consequently, we do find of extreme importance the analysis of firms pricing strategies, under the implementation of reference pricing policies, not only because pharmaceutical firms (tacit) pricing behavior might compromise the endeavour of cost containment of this policy, but also its perverse consequences under a competition policy context. The aim of this article is to analyze whether reference pricing policies facilitate higher prices allowing firms to exert market power and consequently restrict competition and increase prices.

Even though the existing literature on Reference Pricing has been mainly empirical, some authors have contributed to the analysis through the development of theoretical frameworks (Danzon and Chao 2000; Danzon and Liu 1996; Merino-Castelló 2003; Mestre-Ferrandiz 2001; Morton 1999). Among these studies, two deserve special attention given their proximity to the model we aim at developing. In the work by Mestre-Ferrandiz (2001), the author compares the impact of a reference price and a co-payment system in pharmaceutical market with generic competition. Using a horizontal differentiated model where two firms compete *á la Bertrand*, the author concludes that, just for some reference price level, a reference pricing policy can control pharmaceutical expenditure and reduce drug prices. Merino-Castelló (2003), studies the impact of Reference Pricing on the price setting strategies of pharmaceutical firms (generic and branded) on a vertical product differentiated model. The author concludes that reference pricing is indeed effective in enhancing price competition as, after reference pricing had been implemented, branded prices decrease while generic prices remain constant. Nevertheless, this price competition increases the usage of branded drugs in detriment of generics.

The study of pricing behavior is not fully contemplated in the above mentioned articles. Even though the analysis by Merino-Castelló and Mestre-Ferrandiz focus on the impact of reference pricing on firms' pricing strategies, the simplifying assumptions of their set ups do not allow to conclude on this matter. Indeed, our analysis differs from the two above mentioned contributions primarily on the envisaged purpose and, secondly, on the framework used. In effect, in our analysis we study explicit reference pricing formulations as well as consider a different timing of implementation of the policy in order to better fit reality.

The paper is organized as follows. Section 2 provides a detailed description of the framework. Section 3 presents the equilibrium of the game for the different reference pricing strategies. Section 4 introduces vertical product differentiation. Finally we discuss the results and conclude on sections 5 and 6, respectively.

2 The model

Consider a market with two pharmaceutical firms, indexed 1 and 2, and a continuum of consumers. Drugs are horizontally-differentiated being located in an unidimensional characteristics space in an unit interval $[0, 1]$ (in the spirit of Hotelling (1929)). Each firm i for $i = 1, 2$ then, produces a distinct variety of drug at an identical and constant marginal cost c, which (for the sake of simplicity) is standardized to zero: firm 1 produces drug x_1 and firm 2 produces drug x_2. As the strategic location game is not modelled here, the drug varieties will be considered as exogenously given, and we will assume, without loss of generality, that firm 2's variety is located at the right of firm 1's one, i.e., $x_2 > x_1$.

We analyze a finite dynamic game, in which duopolists compete by non-cooperatively setting prices in two subsequent periods: let $p_{i,t}$ be the price charged by firm i at period t , with $i = 1, 2$ and $t = 1, 2$. Each firm chooses strategies in any period to maximize its own profit function π_i for $i = 1, 2$.

Consumers differ on their tastes for drugs. Each consumer is assumed to have a most preferred drug $z \in [0, 1]$ that is given by her location on the line segment. We assume a mass of consumers standardized to one and uniformly distributed along the unit interval. Consumers are endowed with a finite instant utility from treatment k equal across all the individuals.

We first describe the two-stage game where no public regulation is in force. The game is genuinely repeated, in that, in both stages, firms compete by setting simultaneously and non-cooperatively prices which are only affecting their payoffs in that period. The finite game will then be solved backwards by looking at the Subgame Perfect Nash Equilibria. We then characterize the dynamic game when reference pricing is introduced by the regulator.

2.1 Demand

For the moment, assume patients are not reimbursed through a reference pricing policy, thus bearing all the cost of bought drugs. However, in order to fully capture the consumers' behavior in the pharmaceutical markets, we do not force all the patients to consume one variety of drug, i.e., there are possible non-buyers[1]. In fact, given preferences, drug varieties and prices, consumers decide whether to buy one unit of drug 1, one unit of drug 2 or whether not buy any drug at all.

We assume that, when a consumer does not buy any of the drugs, her utility is $U(z;0) = 0$. On the other hand, the utility derived by a consumer located at $z \in [0,1]$ from buying drug $i = 1, 2$ is given by

$$U = k - p_i - t\,|z - x_i|$$

where we set the constant marginal cost of distance t equal to 1 so that $|z - x_i|$ is the loss in utility incurred by a consumer located at z consuming drug x_i at price p_i.

Parameter k represents consumers' instant utility from treatment, equal across patients, and measures the common willingness to pay for any unit of a drug. One can think of it either as the maximum amount a consumer will pay for a drug when deciding between two different treatments or as the main improvement in health status from consuming the pharmaceutical treatment.

The instant utility from treatment allows our analysis to account for different structures, as, depending on the value of k, the market will be partly or fully covered. Intuitively, (a) for sufficiently high levels of the instant utility parameter, all the consumers buy some variety of the differentiated drug and, therefore, the market results being fully covered. On the other hand, (b) for intermediate levels of the instant utility parameter, consumers located at the edges of the market may not consume any of the drug varieties. Finally, (c) for sufficiently low levels of the instant utility parameter, consumers whose preferred drug varieties are located towards the centre of the market might also be better off by not buying any drug. In this case firms behave as local monopolists, selling only in their neighbourhood.

The above market configurations can be represented by the following diagrams,

[1] This feature was first intoduced in horizontally diferentiated models by Economides (1986). The modeling of this feature follows closely his set-up.

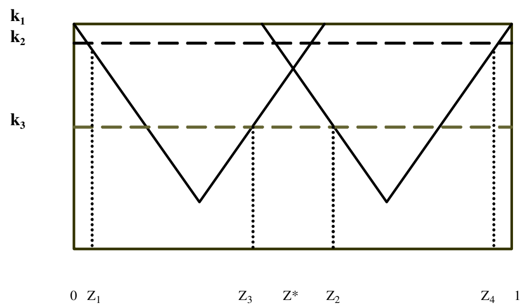


Figure 1: Market structures

Formally, denote $\overline{z}$ as the location of the consumer who is indifferent between buying the drug produced by firm 1 and the one produced by firm 2. Furthermore, let z_1 be the location of the consumer indifferent between buying drug 1 or not buying any of the existing drug varieties in the market, and z_4 the consumer indifferent between buying drug 2 or not buying anything.

As patients derive disutility as measured by the distance between their most preferred drug and the drug they eventually buy, for all the consumers' location such that $z \in [0, z_1[$, it holds that $U(z; x_2) < U(z; x_1) < U(z; 0)$: a consumer located at $z \in [0, z_1[$ is better off by not buying a drug than buying any. On the other hand, for all the consumers whose location are in the interval $z \in]z_1, \overline{z}[$, we have that $U(z; 0) < U(z; x_2) < U(z; x_1)$: consumers located in the range $z \in]z_1, \overline{z}[$ prefer buying firm's 1 drug than buying drug 2 or than not buying any drug at all. Equivalently, for $z \in]\overline{z}, z_4[$, as $U(z; x_1) < U(z; 0) < U(z; x_2)$, consumers obtain a higher utility from buying drug variety 2 than buying from 1 or no drug at all. Finally, also all the consumers located in the segment $z \in]z_4, 1]$, are better off by not buying any drug at all: $U(z; x_1) < U(z; x_2) < U(z; 0)$.

Therefore, the locations of the marginal customers z_1, z_4 and of $\overline{z}$, the one indifferent among two varieties, are the solutions of $U(z; 0) = U(z; x_1)$, $U(z; x_2) = U(z; 0)$ and $U(z; x_1) = U(z; x_2)$ respectively:

$$z_1 = p_1 + x_1 - k \tag{1}$$

$$\overline{z} = \frac{(p_2 - p_1) + (x_1 + x_2)}{2} \tag{2}$$

$$z_4 = k + x_2 - p_2 \tag{3}$$

As each consumer demands just one unit of drug, total demand is given by $D = \int_{z_{1t}}^{z_4 t} f(z)\, dz$ with $D_1 = \int_{z_{1t}}^{\overline{z}_t} f(z)\, dz$ being served by firm 1 and the remaining $D_2 = \int_{\overline{z}_t}^{z_{4t}} f(z)\, dz$ consumers by firm 2.

With z uniformly distributed on the support $[0,1]$ firms' demands in period t are then given by,

$$D_{1,t} = \overline{z}_t - z_{1t} = \frac{p_{2,t} - 3p_{1,t} + x_{2,t} - x_{1,t} + 2k}{2} \tag{4}$$

$$D_{2,t} = z_{4t} - \overline{z}_t = \frac{p_{1,t} - 3p_{2,t} + x_{2,t} - x_{1,t} + 2k}{2} \tag{5}$$

Thus, whenever $z_1 > 0$ and $z_4 < 1$, the model in fact describes the case where the instant utility from treatment k takes intermediate values of k and the consumers at the edges of the market choose to not buy any of the drug varieties. In this paper we will focus on this case only, referring to it as the *competitive scenario*.

2.2 Equilibrium

Being the model a game of perfect information with sequential stages of simultaneous moves, the relevant solution concept for the game is clearly the *Subgame Perfect Nash Equilibrium.*

In particular, finiteness in the number of stages allows us to proceed by *backward induction.* First, we will look for the equilibrium price configurations in the second and last period, then, we will solve for the mutually optimal prices in the first stage, and we will describe the *equilibrium price* strategies of the overall game. For simplicity, in the analysis we will only focus on *pure strategies* Subgame Perfect Nash Equilibrium.

Given the demand functions as defined on (4) and (5), we observe from a comparative statics analysis that in any period, firm's demand is increasing on the rival's price and decreasing in its own price. Indeed,

$$\frac{\partial D_{1,t}}{\partial p_{1,t}} = \frac{\partial D_{2,t}}{\partial p_{2,t}} = -\frac{3}{2} < 0 \tag{6}$$

$$\frac{\partial D_{1,t}}{\partial p_{2,t}} = \frac{\partial D_{2,t}}{\partial p_{1,t}} = \frac{1}{2} > 0 \tag{7}$$

Notice that, in absence of any regulating policy, the strategic pricing decision by the duopolists in either period does not affect in any extent the profits within the other period, and can therefore be seen as separate solution to an identical program $\max_{p_i} \pi_{i,t} = p_{i,t} D_{i,t}$, with $i = 1,2$, and $t = 1,2$. In fact, the equilibrium prices at any stage of the repeated game are the same and the first order conditions are characterized by,

$$\frac{\partial \pi_{1,t}}{\partial p_{1,t}} = p_{1,t}\frac{\partial D_{1,t}}{\partial p_{1,t}} + D_{1,t} = 0 \tag{8}$$

$$\frac{\partial \pi_{1,t}}{\partial p_{2,t}} = p_{2,t}\frac{\partial D_{2,t}}{\partial p_{2,t}} + D_{2,t} = 0 \tag{9}$$

solving these conditions with respect to prices we obtain the pure strategies Nash Equilibrium prices,

$$p^*_{1,t} = p^*_{2,t} = p^* = \frac{\Delta + 2k}{5} \tag{10}$$

where $\Delta = x_2 - x_1 > 0$.

The equilibrium prices are increasing with the distance between firms Δ. Intuitively, higher Δ translate greater degrees of product differentiation and, consequently, stronger market power for both firms leading to higher equilibrium prices.

3 Reference Pricing

We now consider a version of the above model where Reference Pricing is introduced as a reimbursement scheme. In countries, such as Germany and Spain, where pharmaceuticals are reimbursed through a reference pricing system, patients are typically reimbursed a lump sum amount p_r for any homogeneous pharmaceutical cluster, independently of the drug variety bought.

It has been often argued that the reference pricing is delivering not only correct incentives to competing firms but also effective mechanisms to control pharmaceutical expenditure. Here we show that it may, however, facilitate pricing behavior by the firms in the pharmaceutical market.

Despite of the wide range of reference pricing policies[2], the basics of its workings can be generalized in the following expressions

$$\begin{array}{llll} if & p_i & < & p_r \quad P_c = cp_i \\ if & p_i & > & p_r \quad P_c = p_i - p_r + cp_i \end{array}$$

If a drug price (p_i) is lower than the reference price (p_r) level, then the amount paid by the consumer (P_c) is a proportion of the drug price given by the co-payment rate (c) times the drug price (cp_i). For reimbursement systems that do not contemplate co-payments, the consumer pays nothing ($P_c = 0$). Otherwise, for drug prices (p_i) higher than the reference price (p_r) level, the amount paid by the consumer equals the difference between the price and the reference price level plus a proportion of the drug price given by the co-payment rate (c) times the drug price (cp_i). For reimbursement systems that do not contemplate co-payments, the consumer pays simply the extra amount above the reference price level ($p_i - p_r$).

Given that the role of reference is translated by a demand effect consisting of the subtraction of a constant term on the utility function and that, even if the two policies coexist, the marginal impact of one is not affected by the other, in the study of the relative incentives for pricing behavior of reference pricing in

[2] For a complete exposition on the characteristics of this policy in different countries consult Lopez-Casasnovas and Jonsson (2001)

comparison to co-payment policies it suffices to develop two frameworks (one for each policy) having as *status quo* no reimbursement policy and then compare the optimal pricing strategies after the implementation of each policy.

Therefore, in our analysis we will study two scenarios, both characterized by the inexistence of any public reimbursement policy in the first period and its introduction in the beginning of the second period, before pricing strategies are taken by the pharmaceutical firms.

Before describing the model in detail, it may be worthwhile to remind how a reference pricing reimbursement scheme would work. Depending on the market price level relatively to the reference price level the impact of reimbursing consumers through a reference pricing policy will differ. If both drug prices are higher than the reference price level, then, introducing at some point t such a policy mainly affects consumers' demand, by allowing consumers that previously were not buying any drug to start buying. In other words, for any given level of the instant utility from treatment, the locations of the above defined marginal customers are clearly shifted "outward" by the amount of the reference price, while the location of the consumer indifferent between two drug varieties remains unaffected. If firms' pricing strategies are such that charged prices are lower than the reference price level, then the amount financed by the third party payer is just enough to cover that price and, thus, the location of the marginal consumers does not depend neither on the reference price level nor on the drug market price. Finally, if only one firm, say firm 1 (firm 2), prices at a higher level than the reference price, the location of the consumer indifferent between consuming the competitor's drug x_2 (x_1) or opting out from the market will not depend neither on market prices nor on the reference price level. The location of the consumer indifferent between the two drugs will shift to the left (right) with an increase of the reference price while the location of the consumer indifferent between consuming the drug of the competitor and not buying any drug at all shifts right (left), i.e., at the same market price, more consumers are willing to buy the competitor's drug. The impact on profits will follow accordingly to the effects on demand.

Indeed, the consumers utility from consuming drug x_i sold at price $\widehat{p_i}$and reimbursed a lump sum amount $\widehat{p_r}$ whenever $\widehat{p_i} > \widehat{p_r}$ is given by,

$$U(z;x_i) = \begin{cases} k - (\widehat{p_i} - \widehat{p_r}) - |z - x_i| & \text{for } \widehat{p_i} > \widehat{p_r} \\ k - |z - x_i| & \text{for } \widehat{p_i} \leq \widehat{p_r} \end{cases} \tag{11}$$

for $i = 1, 2$ while the utility from no drug consumption remains the same: $U(z; 0) = 0$. Therefore, the marginal consumers are now given by,

For $\widehat{p}_1 > \widehat{p}_r$and $\widehat{p}_2 > \widehat{p}_r$

$$\begin{aligned} \widehat{z}_1 &= \widehat{p}_1 + x_1 - k - \widehat{p}_r \\ \widehat{z}^* &= \overline{z} = \frac{(\widehat{p}_2 - \widehat{p}_1) + (x_1 + x_2)}{2} \\ \widehat{z}_4 &= k + \widehat{p}_r + x_2 - \widehat{p}_2 \end{aligned}$$

For $\widehat{p}_1 \leq \widehat{p}_r$ and $\widehat{p}_2 > \widehat{p}_r$

$$\begin{aligned}\widehat{z}_1 &= x_1 - k \\ \widehat{z}^* &= \overline{z} = \frac{(\widehat{p}_2 - \widehat{p}_r) + (x_1 + x_2)}{2} \\ \widehat{z}_4 &= k + \widehat{p}_r + x_2 - \widehat{p}_2\end{aligned}$$

For $\widehat{p}_1 > \widehat{p}_r$ and $\widehat{p}_2 \leq \widehat{p}_r$

$$\begin{aligned}\widehat{z}_1 &= \widehat{p}_1 + x_1 - k - \widehat{p}_r \\ \widehat{z}^* &= \overline{z} = \frac{(\widehat{p}_r - \widehat{p}_1) + (x_1 + x_2)}{2} \\ \widehat{z}_4 &= k + x_2\end{aligned}$$

For $\widehat{p}_1 \leq \widehat{p}_r$ and $\widehat{p}_2 \leq \widehat{p}_r$

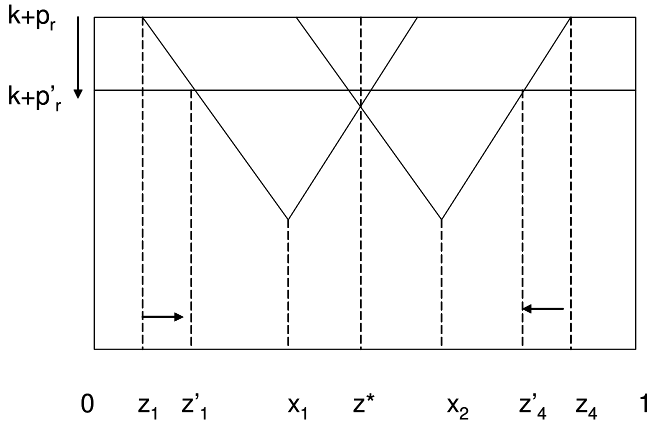
$$\begin{aligned}\widehat{z}_1 &= x_1 - k \\ \widehat{z}^* &= \overline{z} = \frac{(x_1 + x_2)}{2} \\ \widehat{z}_4 &= k + x_2\end{aligned}$$

As a consequence, depending on firms pricing strategies, the total demand in that period will be affected or not by the reimbursement scheme, becoming $D_t = \int_{\widehat{z}_{1t}}^{\widehat{z}_{4t}} f(z)\,dz$ with $D_{1,t} = \int_{\widehat{z}_{1t}}^{\widehat{\widehat{z}}_t} f(z)\,dz$ being served by firm 1 and the remaining $D_{2,t} = \int_{\widehat{\widehat{z}}_t}^{\widehat{z}_{4t}} f(z)\,dz$ consumers by firm 2. With z uniformly distributed on the support $[0,1]$, both firms demand will be characterized by,

$$D_{i,2} = \begin{cases} \frac{\widehat{p}_{-i,2} - 3\widehat{p}_{i,2} + \Delta + 2k}{2} + \widehat{p}_r & \begin{cases} \widehat{p}_i > \widehat{p}_r \\ \widehat{p}_{-i} > \widehat{p}_r \end{cases} \\ \frac{2k + \Delta + \widehat{p}_{-i,2} - \widehat{p}_r}{2} & \begin{cases} \widehat{p}_i \leq \widehat{p}_r \\ \widehat{p}_{-i} > \widehat{p}_r \end{cases} \\ \frac{2k + 3\widehat{p}_r - 3\widehat{p}_{i,2} + \Delta}{2} & \begin{cases} \widehat{p}_i > \widehat{p}_r \\ \widehat{p}_{-i} \leq \widehat{p}_r \end{cases} \\ \frac{\Delta + 2k}{2} & \begin{cases} \widehat{p}_i \leq \widehat{p}_r \\ \widehat{p}_{-i} \leq \widehat{p}_r \end{cases} \end{cases} \quad \text{for } i = 1, 2 \qquad (12)$$

Where $\widehat{p}_{-i}$ is the competitor pricing strategy.

As we can observe from the above demand function we have that if both firms price at a higher level than the reference price then the effect of the latter consists of boosting demand for both firms. If both firms price at a lower level than the reference price, the reference price will not have any effect on demand. And, finally, if one firm prices at a higher level than the reference price while the competitor at a lower level, then reference price will shift outwards (inwards) the demand of the latter (former). Graphically, and for firms prices higher than the reference pricing level,



A shift on reference pricing from p_r to p_r' for $p_i > p_r$ for $i = 1, 2$

3.1 Timing

We consider a two-stage game. In the first stage, the two pharmaceutical firms, in absence of any reimbursement scheme and located at an exogenous distance Δ on the unit interval, compete by simultaneously and non-cooperatively setting the price for their own drug variety. The characteristics of the consumers and the demand are the ones described in the previous section.

At the beginning of the second stage, the government observes the prices $\{\widehat{p}_{1,1}, \widehat{p}_{2,1}\}$ as set up by the firms at the first stage, and fixes a reference price $\widehat{p_r}$ according to a particular function $\widehat{p_r}\left(\widehat{p}_{1,1}, \widehat{p}_{2,1}\right)$ which is common knowledge. In the second period, given such a reference price, the two firms compete anew by setting simultaneously and independently the prices for their drug varieties $\widehat{p}_{1,1}, \widehat{p}_{2,1}$.

Clearly, because of the introduction of the reference price policy, firms' profits in the last stage will depend on the previous period pricing strategies via the impact of reference pricing on the demand function. In fact, the latter is now depending not only on the pricing strategies in the last stage, but also on the reference price:

$$D_{1,2} = f(\widehat{p}_{1,2}, \widehat{p}_{2,2}, \widehat{p_r}\left(\widehat{p}_{1,1}, \widehat{p}_{2,1}\right)) \tag{13}$$

Therefore, as the reference pricing function $\widehat{p_r}\left(\widehat{p}_{1,1}, \widehat{p}_{2,1}\right)$ is in fact common knowledge, the rational firms would be able to anticipate the effects of their decisions at the first period on the subsequent stage, and they would consequently optimize taking the latter into account.

Being $\widehat{p}_i$ the drug price of firm i, c the marginal cost of producing the drug standardized to zero, $\delta \in [0,1]$ is the common discount factor, $\pi_{i,t}$ the profit gained by firm i at stage t, and D_i the demand faced by firm i, the present discount values of all future profits for the duopolists are given by

$$\begin{aligned} PDV_{1,1} &= \pi_{1,1} + \delta\pi_{1,2} \\ &= \widehat{p}_{1,t} D_{1,1}(\widehat{p}_{1,1}, \widehat{p}_{2,1}) + \delta\widehat{p}_{1,2} \qquad (14) \\ &\quad D_{1,2}(\widehat{p}_{1,2}, \widehat{p}_{2,2}, \widehat{p_r}\,(\widehat{p}_{1,1}, \widehat{p}_{2,1})) \qquad (15) \end{aligned}$$

and, analogously for firm 2,

$$\begin{aligned} PDV_{2,1} &= \pi_{2,1} + \delta\pi_{2,2} \\ &= \widehat{p}_{2,t} D_{2,1}(\widehat{p}_{1,1}, \widehat{p}_{2,1}) + \delta\widehat{p}_{2,2} \qquad (16) \\ &\quad D_{2,2}(\widehat{p}_{1,2}, \widehat{p}_{2,2}, \widehat{p_r}\,(\widehat{p}_{1,1}, \widehat{p}_{2,1})) \qquad (17) \end{aligned}$$

Therefore, we will now solve, backwards, the dynamic finite game looking for the Subgame Perfect Nash Equilibria. First we will investigate, for any level of the reference pricing, the Nash equilibria of the pricing game at the last stage. Then, we will go back to the first period to identify which price would be selected by any duopolist in order to maximize its own discount value of future earnings, thus also taking into account the effects on the equilibrium value of the reference price.

3.2 Last Stage

In this stage, given the level of reference price $\widehat{p_r}\,(\widehat{p}_{1,1}, \widehat{p}_{2,1})$ as previously determined by the government, the firms compete simultaneously in prices in order to maximize their own profit in the second period only. Being $\widehat{p}_i$ the drug price of firm i (with $i = 1,2$) and D_i the demand faced by firm i, the duopolists profit functions at the last period π_i are given by

$$\pi_{i,2} = \widehat{p}_{i,2} D_{i,2}(\widehat{p}_{i,2}, \widehat{p}_{-i,2}, \widehat{p_r}\,(\widehat{p}_{i,1}, \widehat{p}_{-i,1})) \quad i = 1,2 \qquad (18)$$

Given that the demand is given by four tiers according to (12) also profits will be. Therefore, one must study what happens for both cases $\{\widehat{p}_{i,2} \leq p_r, \forall \widehat{p}_{-i,2}\}$ and $\{\widehat{p}_{i,2} > \widehat{p_r},\ \forall \widehat{p}_{-i,2}\}$ for $i = 1,2$. Suppose that firm i sets a price such that $\widehat{p}_{i,2} \leq \widehat{p_r}$. If that is the case demand will not depend on the firm, own, pricing strategies indeed it is given by,

$$\begin{aligned} D_i &= \frac{2k + \Delta + \widehat{p}_{-i,2} - \widehat{p_r}}{2} \qquad if \quad \widehat{p}_{-i,2} > \widehat{p_r} \\ D_i &= \frac{\Delta + 2k}{2} \qquad if \quad \widehat{p}_{-i,2} \leq \widehat{p_r} \end{aligned}$$

The profit function of firm i is, then, given by,

$$\begin{aligned} \pi_{i,2} &= \widehat{p}_{i,2} D_{i,2}(\Delta, k; \widehat{p}_{-i,2}) \quad if \quad \widehat{p}_{-i,2} > \widehat{p}_r \\ \pi_{i,2} &= \widehat{p}_{i,2} D_{i,2}(\Delta, k) \quad if \quad \widehat{p}_{-i,2} \leq \widehat{p}_r \end{aligned}$$

Maximizing with respect to prices, the first order conditions are then given by

$$\frac{\partial \pi_{i,2}}{\partial \widehat{p}_{i,2}} = D_{i,2}(\Delta, k; \widehat{p}_{-i,2}) > 0 \ \forall \widehat{p}_{i,2}, \ i = 1, 2$$

Consequently, in the optimum, $\widehat{p}^*_{i,2} \rightarrow +\infty$. Therefore, the condition for which this optimum is defined $\widehat{p}_{i,2} \leq \widehat{p}_r$ is violated, i.e., for every reference price value it is always optimal to price above it[3]. By symmetry, the same reasoning applies to the competitor. Therefore we can focus our analysis for the case where $\widehat{p}_{i,2} > \widehat{p}_r$ with $i = 1, 2$.

Maximizing profits with respect to $\widehat{p}_{1,2}$ and $\widehat{p}_{2,2}$ the first order conditions are given respectively by,

$$\frac{\partial \pi_{1,2}}{\partial \widehat{p}_{1,2}} = \widehat{p}_{i2} \frac{\partial D_{1,2}}{\partial \widehat{p}_{i2}} + D_{i2} = 0 \tag{19}$$

$$\frac{\partial \pi_{2,2}}{\partial \widehat{p}_{2,2}} = \widehat{p}_{i2} \frac{\partial D_{2,2}}{\partial \widehat{p}_{2,2}} + D_{j2} = 0 \tag{20}$$

For $\widehat{p}_{i,2} > \widehat{p}_r$, it is immediately reckoned that the Nash Equilibrium prices of the second stage will be superior to the ones found in the previous model without reference pricing. In fact, for the left hand side of the above conditions being larger under a reference price policy than in the case where $\widehat{p}_r = 0$, it only needs to hold that the demand is indeed increasing with the reference pricing, $\frac{\partial D_{i2}}{\partial \widehat{p}_r} > 0$ ($\frac{\partial D_{i2}}{\partial \widehat{p}_r} > 0$), which is always true as,

$$D_{1,2} = \widehat{z}^* - \widehat{z}_1 = \frac{\widehat{p}_{2,2} - 3\widehat{p}_{1,2} + \Delta + 2k}{2} + \widehat{p}_r \tag{21}$$

$$D_{2,2} = \widehat{z}_4 - \widehat{z}^* = \frac{\widehat{p}_{1,2} - 3\widehat{p}_{2,2} + \Delta + 2k}{2} + \widehat{p}_r \tag{22}$$

where, again, $\Delta = x_2 - x_1 > 0$. Analytically, given that the introduction of reference pricing corresponds to a positive linear transformation of the (concave) profit function, the global maximum of the new function is higher than the analogous of the initial profit function.

In fact, solving the system of two equations, the equilibrium pricing strategies are found to be[4]

[3] Given that this analysis applies to the remaining different scenarios of the paper we will through out omit it and simply analyse the existence of second stage equilibrium for profit functions defined for prices $\widehat{p}_{m,t=2} > \widehat{pr}$ with $m = i, j$

[4] This optimum is valid for $\widehat{p}_{m,t=2} > \widehat{pr}$, i.e., for $\widehat{pr} < \frac{C}{3}$. Given that $\widehat{pr} = \min\{\widehat{p}_{i,t=1}, \widehat{p}_{j,t=1}\}$ as $\widehat{p}^*_{i,t=1} = \widehat{p}^*_{j,t=1} = p^*$ then $\widehat{pr} = p^* = \frac{\Delta + 2k}{5} = \frac{C}{5} \Longrightarrow \widehat{pr} < \frac{C}{3}$ is always true.

$$\widehat{p}_{1,2}^{*} = \widehat{p}_{2,2}^{*} = \frac{\Delta + 2k + 2\widehat{p_r}\left(\widehat{p}_{1,1}, \widehat{p}_{2,1}\right)}{5}$$

As expected, equilibrium prices are increasing in the reservation and reference prices as well as on product heterogeneity (given by the distance between the two drugs locations Δ).

Comparing these price levels $(\widehat{p}_{1,2}^{*}, \widehat{p}_{2,2}^{*})$ with the ones arising from the game without reference pricing (p^{*}) we have,

$$\widehat{p}_{1,2}^{*} - p^{*} = \widehat{p}_{2,2}^{*} - p^{*} = \frac{2}{5}\widehat{p_r}\left(\widehat{p}_{1,1}, \widehat{p}_{2,1}\right) > 0$$

That is, with the introduction of reference pricing firms price at a higher level in the last stage (2).

3.3 First Stage

By moving backwards, we now investigate firms' optimal strategies in the first stage. As mentioned above, knowing the way its pricing strategies are affecting the second stage pricing, each firm will choose such a price to maximize its own present discount value of both current and future profits, that is, the individual optimizing behavior is to,

$$\begin{aligned} \max_{\widehat{p}_{1,1}} PDV_{1,1} &= \\ &= \widehat{p}_{1,t} D_{1,1}(\widehat{p}_{1,1}, \widehat{p}_{2,1}) + \delta \widehat{p}_{1,2}^{*} D_{1,2}(\widehat{p}_{1,2}^{*}, \widehat{p}_{2,2}^{*}, \widehat{p_r}\left(\widehat{p}_{1,1}, \widehat{p}_{2,1}\right)) \end{aligned} \tag{23}$$

for firm 1, and to

$$\begin{aligned} \max_{\widehat{p}_{2,1}} PDV_{2,1} &= \\ &= \widehat{p}_{2,t} D_{1,1}(\widehat{p}_{1,1}, \widehat{p}_{2,1}) + \delta \widehat{p}_{2,2}^{*} D_{1,2}(\widehat{p}_{1,2}^{*}, \widehat{p}_{2,2}^{*}, \widehat{p_r}\left(\widehat{p}_{1,1}, \widehat{p}_{2,1}\right)) \end{aligned} \tag{24}$$

for firm 2, where $\delta \in [0, 1]$ is the common discount factor.

Plugging in the expressions for the second stage equilibrium prices $\widehat{p}_{1,2}^{*} = \widehat{p}_{2,2}^{*} = \frac{\Delta+2k+2\widehat{p_r}(\widehat{p}_{1,1},\widehat{p}_{2,1})}{5}$, and maximizing with respect to $(\widehat{p}_{1,1}, \widehat{p}_{2,1})$ the equilibrium is described by the following first order conditions,

$$\frac{\partial PDV_{1,1}}{\partial \widehat{p}_{1,1}} = \widehat{p}_{1,1}\frac{\partial D_{1,1}}{\partial \widehat{p}_{1,1}} + D_{1,1} + \delta \widehat{p}_{1,2}^{*}\frac{\partial \widehat{p_r}}{\partial \widehat{p}_{1,1}}\left[\frac{\partial D_{1,2}}{\partial \widehat{p}_{2,2}^{*}}\frac{\partial \widehat{p}_{2,2}^{*}}{\partial \widehat{p_r}} + \frac{\partial D_{1,2}}{\partial \widehat{p_r}}\right] = 0$$

Analogously, for firm 2,

$$\frac{\partial PDV_{2,1}}{\partial \widehat{p}_{2,1}} = \widehat{p}_{2,1}\frac{\partial D_{2,1}}{\partial \widehat{p}_{2,1}} + D_{2,1} + \delta \widehat{p}_{2,2}^{*}\frac{\partial \widehat{p_r}}{\partial \widehat{p}_{2,1}}\left[\frac{\partial D_{2,2}}{\partial \widehat{p}_{1,2}^{*}}\frac{\partial \widehat{p}_{1,2}^{*}}{\partial \widehat{p_r}} + \frac{\partial D_{2,2}}{\partial \widehat{p_r}}\right] = 0$$

From the latter conditions, we can thus state the following result.

Proposition 1 *For $\frac{\partial \widehat{p_r}}{\partial \widehat{p}_{1,1}} \geq 0$ and $\frac{\partial \widehat{p_r}}{\partial \widehat{p}_{2,1}} \geq 0$ the Nash Equilibrium prices level is at least as high as the equilibrium prices arising in the above game without reference pricing.*

Proof. In fact, by comparing the first order condition, say for firm 1, with the analogous one for the model without reference pricing, an extra term may be observed, given by

$$\Gamma_1 = \delta \widehat{p}^*_{1,2} \frac{\partial \widehat{p_r}}{\partial \widehat{p}_{1,1}} \left[\frac{\partial D_{1,2}}{\partial \widehat{p}^*_{2,2}} \frac{\partial \widehat{p}^*_{2,2}}{\partial \widehat{p_r}} + \frac{\partial D_{1,2}}{\partial \widehat{p_r}} \right]$$

This term reflects the impact of today's pricing strategies on tomorrow profits. As, from the discussion above, $\frac{\partial D_{1,2}}{\partial \widehat{p}_{2,2}} > 0$, $\frac{\partial \widehat{p}_{2,2}}{\partial \widehat{p_r}_{t=2}} \geq 0$, $\frac{\partial D_{1,2}}{\partial \widehat{p_r}_{t=2}} > 0$, and $\frac{\partial \widehat{p_r}_{t=2}}{\partial \widehat{p}_{1,1}} \geq 0$ it is promptly reckoned that $\Gamma_1 \geq 0$. Therefore, since the introduction of reference pricing is translated into a linear positive increasing transformation of the (concave) profit function, the optimal strategy by any firm necessarily implies to set up a greater or equal equilibrium price level than the corresponding one for the game with no reference pricing. ■

The latter analysis, provides a first insight on the effect of reference price policies upon the duopolists' behavior previous to its introduction: in order to affect the coming regulation policy, firms may have incentives to charge higher prices.

3.4 Different reference price policies

In order to shed some brighter light on the impact of reference pricing on firms' incentives, however, we need to specify in greater detail the exact functional form of $\widehat{p_r}(\widehat{p}_{1,1}, \widehat{p}_{2,1})$, according to which the reference price is, actually, computed, by the third party payer, as a function of the observed pricing strategies.

Here we investigate two main specific adaptive rules corresponding to the ones that have mostly been adopted by policy makers in the last years. Indeed, several countries (such as Australia, British Columbia and New Zealand) have opted for setting a reference price at a level of the *lowest* observed price actually charged by firms in the past.

Other countries (such as Germany and the Netherlands), on the other hand, have, instead, opted for taking into account all the distribution of prices charged by firms in the previous period, for instance, by computing an index linearly combining *any* observed prices.

While the latter may be regarded as a more informative adaptive rule, the interesting feature of the former policy seems to also hinge on the difficulties in the equilibrium computation caused by the inevitable discontinuity in the profit functions.

Min case: $\widehat{p_r}_t = \min\{\widehat{p}_{1,t-1}, \widehat{p}_{2,t-1}\}$ We start investigating the case where the regulatory policy consists of setting a reference price at the level of the lowest observed price in the last period: $\widehat{p_r}_t = \min\{\widehat{p}_{1,t-1}, \widehat{p}_{2,t-1}\}$.

The identification of the Nash equilibrium pricing strategies in such a case is hindered by the fact that a firm's payoff is not a continuous function of its own charged price, depending, at the contrary, on which price is the minimum. Nevertheless, we are able to show that the two-stage game has indeed a unique Subgame Perfect Nash equilibrium.

In fact, for any level of the reference price $\widehat{p_r} = \min\{\widehat{p}_{1,1}, \widehat{p}_{2,1}\}$, the equilibrium prices at the second stage are uniquely determined as the symmetric strategies,

$$\widehat{p}^*_{i,2} = \frac{\Delta + 2k + 2\min\{\widehat{p}_{1,1}, \widehat{p}_{2,1}\}}{5}$$

with $i = 1, 2$, and $\Delta = x_2 - x_1 > 0$. Therefore, firms price above the price level arising under a scenario without reference pricing.

Then, define, as above, $p^* = \frac{\Delta+2k}{5}$ as the symmetric equilibrium price in the absence of reference pricing, C as a strictly positive expression standing for $\Delta + 2k$, and ε an infinitesimal positive amount. Therefore, we will now show the following result,

Proposition 2 *The pair of symmetric pricing strategies*

$$\sigma_i = \widehat{p}^*_{i,1} = p^*; \widehat{p}^*_{i,2} = \frac{\Delta + 2k + 2\widehat{p_r}}{5},\ i = 1, 2$$

represents the unique subgame perfect Nash equilibrium in the two-stage pricing game with reference price of the type $\widehat{p}_{rt} = \min\{\widehat{p}_{1,t-1}, \widehat{p}_{2,t-1}\}$.

Proof. In fact, let's start by assuming that firm 2 pricing optimal strategy coincides with the equilibrium price in the absence of reference pricing: $\widehat{p}^*_{2,1} = p^* = \frac{\Delta+2k}{5}$. To study firm's 1 optimal response pricing strategies, we may start asking whether there would be any profitable deviations from also charging the same price level $\widehat{p}^*_{1,1} = p^* = \frac{\Delta+2k}{5}$. Denote by PDV_1^* firm's 1 present discount value of profits' stream when pricing at $\widehat{p}^*_{1,1} = p^*$, p^* will be a best response at the first stage to 2's strategy if and only if

$$PDV_1^* > PDV_1'\Big|_{p'_{1,1}=p^*\pm\varepsilon}$$

with ε being a positive, though possibly infinitesimal, amount. As a matter of fact, by computing the difference on the discount values it turns out that they are, indeed, strictly positive in both directions:

$$\begin{aligned} PDV_1^* - PDV_1'\Big|_{p'_{1,1}=p^*+\varepsilon} &= \frac{3}{2}\varepsilon^2 > 0 \\ PDV_1^* - PDV_1'\Big|_{p'_{1,1}=p^*-\varepsilon} &= \varepsilon^2\left(\frac{3}{2} - \frac{6}{25}\delta\right) + \\ +\varepsilon\delta\frac{42}{125}(\Delta + 2k) &> 0 \end{aligned}$$

Given the symmetry of such a game, the same line of reasoning is then holding for firm 2. This implies that we have in fact proved that the pair of symmetric strategies $(\widehat{p}^*_{i,1}, \widehat{p}^*_{i,2}) = (\frac{\Delta+2k}{5}, \frac{\Delta+2k+2\widehat{p_r}}{5})$, with $i = 1,2$, is a subgame perfect Nash equilibrium in the two-stages pricing game.

However, we still need to show that

$$\sigma_i = \left(\widehat{p}^*_{i,1} = \frac{\Delta+2k}{5}; \widehat{p}^*_{i,2} = \frac{\Delta+2k+2\widehat{p_r}}{5}\right)$$

for $i = 1,2$, is the *unique* symmetric subgame perfect Nash equilibrium (SPNE). We then control whether any pair $\sigma_i = \left(\widehat{p}^*_{i,1} = p^* \pm x; \widehat{p}^*_{i,2} = \frac{\Delta+2k+2\widehat{p_r}}{5}\right)$, $i = 1,2$ is a SPN equilibrium. To see it, suppose that, at the first stage, firm 2 fixes a price $\widehat{p}_{2,1} = p^*+x$. Now, taking as given such a price charged by 2, it is clearly not an optimal response by firm 1 to charge any price above $\widehat{p}_{2,1} = p^*+x$. In fact, by doing so it would suffer losses compared to the earnings gained by also pricing an identical $\widehat{p}_{1,1} = p^*+x$, as

$$\widehat{PDV}_1 \left|_{\widehat{p}_{1,1}=p^*+x} - PDV_1' \right|_{p'_{1,1}=p^*+x+\varepsilon} = \frac{3}{2}\varepsilon^2 + \frac{5}{2}x\varepsilon > 0$$

Nevertheless, one could argue that it still might be optimal for firm 1 to undercut firm 2 price. Indeed, by direct computation, it turns out that, there exists an ε for which deviating from charging a symmetric price $\widehat{p}_{1,1} = p^*+x$ to a lower one is profitable. In fact,

$$\begin{aligned} PDV_1 \left|_{\widehat{p}_{1,1}=p^*+x} - PDV_1' \right|_{p'_{1,1}=p^*+x-\varepsilon} &= \varepsilon^2\left(\frac{3}{2} - \frac{16}{25}\delta\right) + x\varepsilon\left(\frac{32}{25}\delta - \frac{5}{2}\right) + \\ &\quad +\varepsilon\delta\frac{87}{125}(\Delta+2k) \end{aligned}$$

for $\delta \in [0,1]$, is so that

$$\begin{aligned} PDV_1 \left|_{\widehat{p}_{1,1}=p^*+x} - PDV_1' \right|_{p'_{1,1}=p^*+x-\varepsilon} &> 0 \quad \text{for} \quad \varepsilon > \frac{625x - 174\delta C - 320\delta x}{5(75-32\delta)} \\ PDV_1 \left|_{\widehat{p}_{1,1}=p^*+x} - PDV_1' \right|_{p'_{1,1}=p^*+x-\varepsilon} &< 0 \quad \text{for} \quad \varepsilon < \frac{625x - 174\delta C - 320\delta x}{5(75-32\delta)} \\ PDV_1 \left|_{\widehat{p}_{1,1}=p^*+x} - PDV_1' \right|_{p'_{1,1}=p^*+x-\varepsilon} &= 0 \quad \text{for} \quad \varepsilon = \frac{625x - 174\delta C - 320\delta x}{5(75-32\delta)} \end{aligned}$$

Then, in the first case there exists a $\varepsilon > 0$ such that it is profitable to undercut any $\widehat{p}_{2,1} = p^*+x$. Therefore any pair of strategies

$$\sigma_i = \left(\widehat{p}^*_{i,1} = \frac{\Delta+2k}{5} + x; \widehat{p}^*_{i,2} = \frac{\Delta+2k+2\widehat{p_r}}{5}\right)$$

can never be a Subgame Perfect Nash Equilibrium.

Suppose now that, at the first stage, firm 2 fixes a price $\widehat{p}_{2,1} = p^*-x$ with $x > 0$. Now, taking as given such a price charged by 2, it is clearly not an optimal response by firm 1 to charge any price above $\widehat{p}_{2,1} = p^*-x$, i.e.,

$\widehat{p}_{2,1} = p^* - x + \varepsilon$ for $\varepsilon > 0$. In fact, by doing so it would suffer losses compared to the earnings gained by also pricing an identical $\widehat{p}_{1,1} = p^* - x$, as

$$PDV_1 \left|_{\widehat{p}_{1,1}=p^*-x} - PDV_1' \right|_{p_{1,1}'=p^*-x+\varepsilon} = \varepsilon^2 \left(\frac{3}{2} - \frac{6}{25}\delta\right) + x\varepsilon \left(\frac{5}{2} - \frac{12}{25}\delta\right) + +\varepsilon\delta\frac{42}{125}(\Delta + 2k)$$

for any $\varepsilon > 0$,

$$PDV_1 \left|_{\widehat{p}_{1,1}=p^*-x} - PDV_1' \right|_{p_{1,1}'=p^*-x+\varepsilon} > 0$$

Nevertheless, one could argue that it still might be optimal for firm 1 to undercut firm 2 price. Indeed, by direct computation, it turns out that, there exists an ε for which deviating from charging a symmetric price $\widehat{p}_{1,1} = p^* - x$ to a lower one, $\widehat{p}_{2,1} = p^* - x - \varepsilon$, is profitable. In fact,

$$PDV_1 \left|_{\widehat{p}_{1,1}=p^*-x} - PDV_1' \right|_{p_{1,1}'=p^*-x-\varepsilon} = \frac{3}{2}\varepsilon^2 - \frac{5}{2}x\varepsilon$$

Therefore, given that 2 is charging a price $\widehat{p}_{2,1} = p^* - x$, 1's best response is to charge $\widehat{p}_{1,1} = p^* - x - \varepsilon$. Therefore there exists an $\varepsilon > 0$ such that it is profitable to undercut any $\widehat{p}_{2,1} = p^* - x$. Consequently, any pair of strategies $\sigma_i = \left(\widehat{p}_{i,1}^* = \frac{\Delta+2k}{5} - x; \widehat{p}_{i,2}^* = \frac{\Delta+2k+2\widehat{p_r}}{5}\right)$ can never be a Subgame Perfect Nash Equilibrium. This implies that, the symmetric pair of strategies $\sigma_i = \left(\widehat{p}_{i,1}^* = p^*; \widehat{p}_{i,2}^* = \frac{\Delta+2k+2\min\{\widehat{p}_{1,1},\widehat{p}_{2,1}\}}{5}\right)$, $i = 1, 2$, is a unique SPNE. ■

Intuitively, as both firms experience increased profits at higher $\widehat{p_r}$ levels and as the latter is an increasing function of firms' pricing strategies, firms have an incentive to increase $\widehat{p_r}$ via higher prices. Nevertheless, for different pricing strategies, in this case, only one firm is able to in fact affect $\widehat{p_r}$. For this firm it is then profitable to sacrifice part of today's profit in order to attain higher profit tomorrow. This firm has an incentive, today, to price at a higher level than what would prevail in the absence of reference pricing as long as its price is lower than the competitor´s. Therefore, it will do so until its price reaches the competitor's price. On the other hand, the competitor pricing strategies in the first period simply affect his first period instantaneous profit. Hence, this firm will have no strategical incentive to exchange today's for tomorrow's profit, and therefore has no incentive to further increase its price today. Moreover, by decreasing its price will trigger price competition and, consequently, force the competitor to decrease its price. Overall, stiffer competition results in lower reference price levels and consequently lower demand and profit tomorrow.

Second case: $\widehat{p_r}_t = (1-\beta)\widehat{p}_{1,t-1} + \beta\widehat{p}_{2,t-1}$ We will now investigate the effect of an alternative regulatory policy, computing the reference price as a linear combination of the past observed prices set by the firms. The reference price is now given by a weighed average of drugs' prices,

$$\widehat{p_r}_t = (1-\beta)\widehat{p}_{1,t-1} + \beta\widehat{p}_{2,t-1}$$

With $\beta \in [0,1]$.

Solving backwards, the Nash equilibrium pricing strategies at the second stage are described by

$$\widehat{p}^*_{1,2} = \widehat{p}^*_{2,2} = \frac{\Delta + 2k + 2\left[(1-\beta)\widehat{p}_{1,1} + \beta\widehat{p}_{2,1}\right]}{5}$$

As before, equilibrium prices are increasing in reference and instant utility from treatment levels and on the degree of differentiation between drugs.

Moving to the first period, by direct computation of the first order conditions it can be seen that the above defined extra terms for firms 1 and 2 are both positive,

$$\begin{aligned} \Gamma_{1,1} &> 0 \\ \Gamma_{2,1} &> 0 \end{aligned}$$

that is, the equilibrium prices are expected to always be higher than in the game without reference pricing. In fact, by maximizing firms' profits with respect to prices and by solving the first order conditions, it turns out that the subgame perfect Nash equilibrium asymmetric pricing strategies are such that,

$$\begin{aligned} \widehat{p}^*_{1,1} &= C\frac{48\delta\beta^2 + 36\delta\beta - 72\delta - 175}{240\delta\beta^2 + 144\delta - 240\delta\beta - 875} \\ &= C\frac{12\delta\left[(2\beta-1)^2 + 7(\beta-1)\right] - 175}{48\delta\left[5\beta(\beta-1)+3\right] - 875} \\ \widehat{p}^*_{2,1} &= C\frac{48\delta\beta^2 - 132\delta\beta + 12\delta - 175}{240\delta\beta^2 + 144\delta - 240\delta\beta - 875} \end{aligned}$$

where C is $\Delta + 2k$.

For low values of β the equilibrium price of drug 1 is increasing with β. For higher levels of β the price of drug 1 is decreasing with β. Concerning the price of drug 2 for sufficiently it is increasing in β, $\forall\beta \in [0,1]$. The lower the weights attached to a firms price on the reference pricing rule, the lower (higher) the price of the drug produced by this firm (the rival) Moreover, both prices are increasing with the instant utility from treatment parameter and the degree of product differentiation. Indeed, for $\widehat{p}^*_{i,1} > 0$, $i = 1,2$, and given that $C > 0$ both prices are increasing in C (with $C = \Delta + 2k$). The price of both drugs 1 and 2 is also increasing with δ. Also this result is intuitive, for higher the values attached to future profits the incentive to sacrifice today's' profits, via increased prices, in order to obtain higher profits tomorrow is stronger.

Therefore the reference price level is given by,

$$\widehat{p_r} = C\frac{120\delta\beta^2 - 120\delta\beta + 72\delta + 175}{875 - 240\delta\beta^2 - 144\delta + 240\delta\beta}$$

Straight forward computations show that the reference price is increasing in C and for $\beta \in \left[0, \frac{1}{2}\right]$ it is decreasing with β while for $\beta \in \left[\frac{1}{2}, 1\right]$ it is increasing with β.

Plugging into the optimal values found for the second stage price game[5],

$$\widehat{p}^*_{1,2} = \widehat{p}^*_{2,2} = \frac{245}{875 - 240\delta\beta^2 - 144\delta + 240\delta\beta}$$

For $\beta \in \left[0, \frac{1}{2}\right[$ second stage prices are increasing with β otherwise, for $\beta \in \left]\frac{1}{2}, 1\right]$ optimal drug prices are decreasing with β.

Comparing the first period equilibrium prices with the equilibrium prices in the game with no regulation we find that even computing reference pricing in terms of linear combination of past observations leads to higher equilibrium prices set by the duopolists:

$$\begin{aligned}
\widehat{p}^*_{1,1} - p^* &= \frac{84C\delta\left(5\beta - 6\right)}{5\left(240\delta\beta^2 + 144\delta - 240\delta\beta - 875\right)} > 0 \\
\widehat{p}^*_{2,1} - p^* &= -\frac{84C\delta\left(5\beta + 1\right)}{5\left(240\delta\beta^2 + 144\delta - 240\delta\beta - 875\right)} > 0
\end{aligned}$$

Interestingly, but not surprisingly, in this case the divergence between the asymmetric equilibrium prices ultimately depends on the announced weights by which the policy mechanism is built. In fact, by rewriting such difference between equilibrium prices as

$$\frac{\widehat{p}^*_{1,1}}{\widehat{p}^*_{2,1}} - 1 = \frac{84\delta\left(2\beta - 1\right)}{48\delta\beta^2 - 132\delta\beta + 12\delta - 175} \tag{25}$$

it can be seen that the denominator is always negative. Therefore, it always holds that

$$\begin{aligned}
\widehat{p}^*_{1,1} &> \widehat{p}^*_{2,1} \quad \text{for} \quad \beta \in \left[0, \frac{1}{2}\right[\\
\widehat{p}^*_{1,1} &= \widehat{p}^*_{2,1} \quad \text{for} \quad \beta = \frac{1}{2} \\
\widehat{p}^*_{1,1} &< \widehat{p}^*_{2,1} \quad \text{for} \quad \beta \in \left]\frac{1}{2}, 1\right]
\end{aligned}$$

[5] As the profit function for which this optimum was calculated exists for prices higher than the reference price level, we still need to impose that $p_{m,t=2} > pr$ that is always true for $\delta < \frac{35}{12\left(5\beta^2 - 5\beta + 3\right)}$

In other words, both firms' prices are higher in presence of reference pricing, but, depending on the value of the weight β upon which the linear combination rule is computed, their relative (asymmetric) distance could be higher or lower. In particular, the higher the weight of the reference pricing rule attributed to a specific firm's price, the higher its equilibrium price relatively to the competitor's. The intuition is clear. In fact, as firms' profits are increasing in the reference price level and as β measures the impact of firm 1 's pricing strategy on reference pricing, the higher the latter, the more profitable it is for firm 1 to sustain higher prices. Contrarily to the outcome of the previous setup, under this reference pricing formulation both prices have an effect on the level of $\widehat{p_r}$. The extent of this influence depends on the weight β that basically works as the "instrument" by which their pricing strategies affect the level of $\widehat{p_r}$.

Different rules comparison Comparing the equilibrium prices obtained under each policy we find that first stage equilibrium prices are always higher when the reference price level is calculated as an average of observed firms' prices. Moreover, while under the first reference pricing rule firms price at an identical level, under the second equilibrium prices differ between firms. Therefore, the reference price level is always lower under the first rule.

On what concerns second period pricing strategies for sufficiently high and low values of β the first reference price rule leads to lower prices while for intermediate values of β results are ambiguous (depend on consumers preferences, on the degree of horizontal differentiation and on the discount factor).

4 Vertical differentiation

We now introduce product vertical differentiation by assuming that one of the drugs has a higher quality relatively to its competitor. Quality can both be interpreted as effective or perceived quality. While the first consists of a product specification such as the coating of a pill or the easiness in the drug in-take, the latter has solely to do with the perception that consumers have of a drug. Despite the level of similarity between two drugs, due to a more effective marketing, brand loyalty or reputation in the market, one drug might be perceived as belonging to a higher quality standard than the other. The importance of such an assumption lies on its ability to better fit a pharmaceutical market where both generic and branded drugs coexist.

Consider now the model analyzed before but with one firm (1) offering some quality q while the other (2) does not. q can be seen as perceived quality, with the firm that offers it being the branded firm while the other the generic firm.

In this set up the utility derived by a consumer located at z from buying drug i at price p_i being reimbursed a lump sum $\widetilde{p_r}$, is given by

$$U(z;x_i) = \begin{cases} k + q - (\widetilde{p_i} - \widetilde{p_r}) - t\,|z - x_i| & \text{for } \widetilde{p_i} > \widetilde{p_r} \\ k + q - t\,|z - x_i| & \text{for } \widetilde{p_i} \leq \widetilde{p_r} \end{cases}$$

for $i = 1, 2$ while the utility from no drug consumption remains the same: $U(z; 0) = 0$. Therefore, the marginal consumers are now given by,

For $\widetilde{p}_1 > \widetilde{p}_r$ and $\widetilde{p}_2 > \widetilde{p}_r$

$$\begin{aligned} \widetilde{z}_1 &= \widetilde{p}_1 - \widetilde{p}_r + x_1 - k - q \\ \widetilde{z}^* &= \overline{z} = \frac{(\widetilde{p}_2 - \widetilde{p}_1) + (x_1 + x_2) + q}{2} \\ \widetilde{z}_4 &= k + x_2 + \widetilde{p}_r - \widetilde{p}_2 \end{aligned}$$

For $\widetilde{p}_1 \leq \widetilde{p}_r$ and $\widetilde{p}_2 > \widetilde{p}_r$

$$\begin{aligned} \widetilde{z}_1 &= x_1 - k - q \\ \widetilde{z}^* &= \overline{z} = \frac{(\widetilde{p}_2 - \widetilde{p}_r) + (x_1 + x_2) + q}{2} \\ \widetilde{z}_4 &= k + \widetilde{p}_r + x_2 - \widetilde{p}_2 \end{aligned}$$

For $\widetilde{p}_1 > \widetilde{p}_r$ and $\widetilde{p}_2 \leq \widetilde{p}_r$

$$\begin{aligned} \widetilde{z}_1 &= \widetilde{p}_1 + x_1 - k - \widetilde{p}_r - q \\ \widetilde{z}^* &= \overline{z} = \frac{(\widetilde{p}_r - \widetilde{p}_1) + (x_1 + x_2) + q}{2} \\ \widetilde{z}_4 &= k + x_2 \end{aligned}$$

For $\widetilde{p}_1 \leq \widetilde{p}_r$ and $\widetilde{p}_2 \leq \widetilde{p}_r$

$$\begin{aligned} \widetilde{z}_1 &= x_1 - k - q \\ \widetilde{z}^* &= \overline{z} = \frac{(x_1 + x_2) + q}{2} \\ \widetilde{z}_4 &= k + x_2 \end{aligned}$$

At higher quality levels the marginal consumer ($\widetilde{z}^*$) indifferent between drugs 1 and 2 has a location in the taste space to the right of the previous marginal consumer. Indeed, higher quality levels increase the degree of (vertical) differentiation between the two drugs rendering the preference of drug 1 relatively to drug 2 stronger and, consequently, increasing the demand for firm 1 and decreasing the demand for firm 2.

Concerning the consumers indifferent between buying and not buying, $\widetilde{z}_1$ and $\widetilde{z}_4$, at higher quality levels, consumers switch from not buying any drug to buying drug 1. On the other hand, as expected, quality has no impact on the decision between buying drug 2 or not buying any drug at all. That is, a consumer located at $z \in [0, \widetilde{z}_1[$ is better off by not buying a drug than buying any. Consumers located in the interval $z \in]\widetilde{z}_1, \widetilde{z}^*[$ prefer buying firm's 1 drug than buying drug 2 or not buying any drug at all. Finally, consumers in the segment $]\widetilde{z}^*, \widetilde{z}_4[$ obtain a higher utility by buying drug two than buying drug one or no drug at all. Thus, $\widetilde{z}_1, \widetilde{z}_4$ and $\widetilde{z}^*$ will be the solution of $U(z;0) = U(z;x), U(z;y) = U(z;0)$ and $U(z;y) = U(z;x)$ respectively, assuming, without loss of generality, unitary transportation costs 1. Consequently the demand functions are given by,

$$D_{1,2} = \begin{cases} \frac{\widetilde{p}_{2,2} - 3\widetilde{p}_{1,2} + \Delta + 2k + 3q + 2\widetilde{p_r}}{2} & \begin{cases} \widetilde{p}_{1,2} > \widetilde{p_r} \\ \widetilde{p}_{2,2} > \widetilde{p_r} \end{cases} \\ \frac{2k + \Delta + \widetilde{p}_{2,2} - \widetilde{p_r} + 3q}{2} & \begin{cases} \widetilde{p}_{1,2} \leq \widetilde{p_r} \\ \widetilde{p}_{2,2} > \widetilde{p_r} \end{cases} \\ \frac{2k + 3\widetilde{p_r} - 3\widetilde{p}_{1,2} + \Delta + 3q}{2} & \begin{cases} \widetilde{p}_{1,2} > \widetilde{p_r} \\ \widetilde{p}_{2,2} \leq \widetilde{p_r} \end{cases} \\ \frac{\Delta + 2k + 3q}{2} & \begin{cases} \widetilde{p}_{1,2} \leq \widetilde{p_r} \\ \widetilde{p}_{2,2} \leq \widetilde{p_r} \end{cases} \end{cases}$$

For firm 1, and for firm 2

$$D_{2,2} = \begin{cases} \frac{\widetilde{p}_{1,2} - 3\widetilde{p}_{2,2} + \Delta + 2k - q + 2\widetilde{p_r}}{2} & \begin{cases} \widetilde{p}_{1,2} > \widetilde{p_r} \\ \widetilde{p}_{2,2} > \widetilde{p_r} \end{cases} \\ \frac{2k + \Delta + 3\widetilde{p_r} - 3\widetilde{p}_{2,2} - q}{2} & \begin{cases} \widetilde{p}_{1,2} \leq \widetilde{p_r} \\ \widetilde{p}_{2,2} > \widetilde{p_r} \end{cases} \\ \frac{2k + \widetilde{p}_{1,2} - \widetilde{p_r} + \Delta - q}{2} & \begin{cases} \widetilde{p}_{1,2} > \widetilde{p_r} \\ \widetilde{p}_{2,2} \leq \widetilde{p_r} \end{cases} \\ \frac{\Delta + 2k - q}{2} & \begin{cases} \widetilde{p}_{1,2} \leq \widetilde{p_r} \\ \widetilde{p}_{2,2} \leq \widetilde{p_r} \end{cases} \end{cases}$$

We will proceed with the analysis for the case $\widetilde{p}_1 > \widetilde{p_r}$ and $\widetilde{p}_2 > \widetilde{p_r}$.[6] The introduction of quality increases the demand of the firm supplying it , i.e., firm's 1 demand, while it decreases firm's 2 demand. Without reference pricing the equilibrium prices in each stage are given by,

$$\begin{aligned} \widetilde{p}^*_{1,2} &= \frac{C}{5} + \frac{17}{35}q \\ \widetilde{p}^*_{2,2} &= \frac{C}{5} - \frac{3}{35}q \end{aligned}$$

Intuitively, vertical product differentiation confers the firm offering quality (firm 1) a higher market power and, thus, allows her to charge higher prices.

Comparing firm 1 price with firm 2

$$\frac{\widetilde{p}^*_{1,1}}{\widetilde{p}^*_{2,1}} - 1 = \frac{147\delta C}{(875 - 81\delta)} > 0$$

As $\widetilde{p}_{2,t} > 0$ implies $7C - 3q > 0$ we have that $\frac{\widetilde{p}_{1,1}}{\widetilde{p}_{2,1}} - 1 > 0$. The branded firm will always price higher than the generic firm. This result is quite intuitive, indeed, a positive (perceived) quality level ($q > 0$) confers some degree of market power to the branded firm what allows for higher mark ups.

[6] As proven before, there exists no equilibrium caracterized by second stage prices below the reference price level. So we will proceed our analysis focusing on prices above the reference price (obviously without constraining the optimization in the search for an equilibrium).

4.1 Reference Pricing

In line with the previous sections we will now the reproduce the analysis by contemplating different reference pricing policies but otherwise in all-equal frameworks.

4.1.1 Min case: $\widetilde{p_r}_t = \min\{\widetilde{p}_{1,t-1}, \widetilde{p}_{2,t-1}\}$

We start investigating the case where the regulatory policy consists in setting a reference price at the level of the lowest observed price in the last period.

With reference pricing, in the second stage firms optimal pricing strategies are[7],

$$\begin{aligned} \widetilde{p}^*_{1,2} &= \frac{C}{5} + \frac{17}{35}q + \frac{2}{5}\widetilde{p_r} \\ \widetilde{p}^*_{2,2} &= \frac{C}{5} - \frac{3}{35}q + \frac{2}{5}\widetilde{p_r} \end{aligned}$$

with $\widetilde{p_r}_t = \min\{\widetilde{p}_{1,t-1}, p_{2,t-1}\}$.

In the first stage firms maximize the present discount value of the profit stream,

$$PDV_{1,1} = \widetilde{p}_{1,1}D_{i1} + \delta\widetilde{p}^*_{1,2}D_{1,2}\left(\widetilde{p}^*_{1,2}, \widetilde{p_r}_2\right)$$

With,

$$\widetilde{p_r} = \min\{\widetilde{p}_{1,1}, \widetilde{p}_{2,1}\}$$

Maximizing with respect to $\widetilde{p}_{1,1}$ and $\widetilde{p}_{2,1}$, the first order conditions are,

$$\frac{\partial PDV_{1,1}}{\partial\widetilde{p}_{1,1}} = \widetilde{p}_{i1}\frac{\partial D_{1,1}}{\partial\widetilde{p}_{1,1}} + D_{1,1} + \delta\widetilde{p}_{1,2}\frac{\partial\widetilde{p_r}}{\partial\widetilde{p}_{1,1}}\left[\frac{\partial D_{1,2}}{\partial\widetilde{p}_{2,2}}\frac{\partial\widetilde{p}_{2,2}}{\partial\widetilde{p_r}} + \frac{\partial D_{1,2}}{\partial\widetilde{p_r}}\right] = 0$$

Analogously, for firm 2,

$$\frac{\partial PDV_{2,1}}{\partial\widetilde{p}_{2,1}} = \widetilde{p}_{j1}\frac{\partial D_{2,1}}{\partial\widetilde{p}_{2,1}} + D_{2,1} + \delta\widetilde{p}_{2,2}\frac{\partial\widetilde{p_r}}{\partial\widetilde{p}_{2,1}}\left[\frac{\partial D_{2,2}}{\partial\widetilde{p}_{1,2}}\frac{\partial\widetilde{p}_{2,2}}{\partial\widetilde{p_r}} + \frac{\partial D_{2,2}}{\partial\widetilde{p_r}}\right] = 0$$

Given the reference pricing rule, the first order conditions will depend on the relation between the two prices.

Suppose that an equilibrium is such that $\widetilde{p}_{1,1} < \widetilde{p}_{2,1}$, then the reference price level will be $\widetilde{p_r}_2 = \widetilde{p}_{1,1}$. Given that $\frac{\partial\widetilde{p_r}}{\partial\widetilde{p}_{1,1}} = 1$, $\frac{\partial\widetilde{p_r}}{\partial\widetilde{p}_{2,1}} = 0$ the equilibrium prices must now satisfied the following conditions,

$$\widetilde{p}_{1,1}\frac{\partial D_{1,1}}{\partial\widetilde{p}_{1,1}} + D_{1,1}\delta\widetilde{p}_{1,2}\left[\frac{\partial D_{1,2}}{\partial\widetilde{p}_{2,2}}\frac{\partial\widetilde{p}_{2,2}}{\partial\widetilde{p_r}} + \frac{\partial D_{1,2}}{\partial\widetilde{p_r}}\right] = 0$$

[7] Equilibrium valid for $\widetilde{p}_{j,2} > \widetilde{pr} \Leftrightarrow \frac{C}{5} - \frac{3}{35}q - \frac{3}{5}\widetilde{pr} > 0$

$$\widetilde{p}_{2,1}\frac{\partial D_{2,1}}{\partial \widetilde{p}_{2,1}}+D_{2,1}=0$$

Solving for the equilibrium prices,

$$\begin{aligned}\widetilde{p}^{*}_{1,1} &= \frac{204\delta q+175C+425q+84\delta C}{125-24\delta}\\ \widetilde{p}^{*}_{2,1} &= \frac{62\delta q+175C-75q-14\delta C}{125-24\delta}\end{aligned}$$

and comparing the two prices,

$$\widetilde{p}^{*}_{1,1}-\widetilde{p}^{*}_{2,1}=\frac{2\left(71\delta q+250q+49\delta C\right)}{125-24\delta}>0$$

we find that the initial assumption is violated, i.e., $\widetilde{p}^{*}_{i1}>\widetilde{p}^{*}_{j1}$. Indeed, there can never exist an equilibrium where the firm with higher market power conferred by higher quality (the branded firm) prices at a lower level.

Assume now that $\widetilde{p}_{1,1}>\widetilde{p}_{2,,1}$, then the reference price level will be $\widetilde{p_r}=\widetilde{p}_{2,1}$. Given that $\frac{\partial \widetilde{p_r}}{\partial \widetilde{p}_{1,1}}=0$, $\frac{\partial \widetilde{p_r}}{\partial \widetilde{p}_{2,1}}=1$ the equilibrium prices must now satisfied the following conditions,

$$\widetilde{p}_{1,1}\frac{\partial D_{1,1}}{\partial \widetilde{p}_{1,1}}+D_{1,1}=0$$

$$\widetilde{p}_{2,1}\frac{\partial D_{2,1}}{\partial \widetilde{p}_{2,1}}+D_{2,1}+\delta\widetilde{p}_{2,2}\left[\frac{\partial D_{2,2}}{\partial \widetilde{p}_{1,2}}\frac{\partial \widetilde{p}_{2,2}}{\partial \widetilde{p_r}}+\frac{\partial D_{2,2}}{\partial \widetilde{p_r}}\right]=0$$

Solving for the equilibrium prices,

$$\begin{aligned}\widetilde{p}^{*}_{1,1} &= \frac{-90\delta q+175C+425q-14\delta C}{125-24\delta}\\ \widetilde{p}^{*}_{2,1} &= \frac{-36\delta q+175C-75q+84\delta C}{125-24\delta}\end{aligned}$$

and comparing the two prices,

$$\widetilde{p}^{*}_{1,1}-\widetilde{p}^{*}_{2,1}=\frac{2\left(-27\delta q+250q-49\delta C\right)}{125-24\delta}$$

we find that the initial assumption, $\widetilde{p}^{*}_{1,1}>\widetilde{p}^{*}_{2,1}$, is verified, as long as

$$q>\frac{49\delta C}{250-27\delta}$$

Therefore, the reference price level is given by,

$$\widetilde{p_r}=\frac{-36\delta q+175C-75q+84\delta C}{125-24\delta}$$

And the second stage equilibrium prices[8],

$$\widetilde{p}^{*}_{1,2} = \frac{3325C + 1008C - 912\delta q + 1075q}{35\,(125 - 24\delta)}$$
$$\widetilde{p}^{*}_{2,2} = \frac{3325C + 1008C - 432\delta q - 1425q}{35\,(125 - 24\delta)}$$

Again in this case, the result is very intuitive. A sufficiently high (perceived) quality level, supplied by the branded firm, reduces price sensitivity of demand what allows the firm to price higher than she would if the two drugs were homogeneous in terms of quality.

Comparing the equilibrium prices with the ones in the absence of reference pricing,

$$\Delta_1 = \widetilde{p}^{*}_{1,1} - \widetilde{p}^{*}_{1,1,p_r=0} = \frac{2\delta\,(7C - 3q)}{125 - 24\delta} > 0$$
$$\Delta_2 = \widetilde{p}^{*}_{2,1} - \widetilde{p}^{*}_{2,1,p_r=0} = \frac{12\delta\,(7C - 3q)}{125 - 24\delta} > 0$$

Both firms price at a higher level than in the absence of reference pricing. but firm 2 prices relatively higher (with respect to the scenario without reference price) than firm 1. In fact,

$$\frac{\widetilde{p}^{*}_{i1} - \widetilde{p}^{*}_{i1,p_r=0}}{\widetilde{p}^{*}_{j1} - \widetilde{p}^{*}_{i1,p_r=0}} < 1$$

The price difference is lower for the branded firm. This result is related to the nature of the demand, indeed one can see reference pricing as an extra incentive for consumption, that is, it will have a positive impact on the number of consumers that actually opt for buying a drug and not on the decision of which drug to buy. But this effect is bounded by the number of potential buyers in the market. If we consider that perceived quality plays the same role, we observe that the extra consumers the branded firm has to gain due to the introduction of reference price will be less than for the generic firm. This price difference can also accrue to the fact that, in this scenario, the reference price affects differently the firms, while it has a positive direct effect on the generic firm pricing strategies in the first stage, the same does not happen for the branded firm.

A further interesting result is that these price gaps are decreasing with the level of quality, indeed $\partial\Delta_1/\partial q < 0$ and $\partial\Delta_2/\partial q < 0$. Hence, the higher the differentiation on quality the lower the incentive for firms to price at higher level with the introduction of reference pricing. Intuitively, given that the reference price setter is firm 2 (the producer of the generic firm) the ability to, profitably,

[8] Valid for $\widetilde{p}_{m,t=2} > \widetilde{pr}$. As $\widetilde{p}_{j,t=2} < \widetilde{p}_{i,t=2}$ it suffices to impose the conditions for which $\widetilde{p}_{j,t=2} > \widetilde{pr}$ holds, i.e., $q > \frac{7}{3}C$

increase prices with the introduction of reference pricing is limited by the degree of product differentiation. The market power conferred to the firm providing quality limits the role of the rival as reference price setter. Naturally, having that the reference price setter is solely determined by the pricing strategies of the latter, the impact of the reference price on the branded drug pricing strategies is constrained in the same way.

Furthermore, $\|\partial\Delta_2/\partial q\| > \|\partial\Delta_1/\partial q\|$. The inverse relation between quality and the above price gaps is stronger for the generic firm, that is to say that the disincentive of pricing higher in the presence of quality is stronger for the generic firm. Therefore, with vertical differentiation even a policy where the reference price is given by the minimum observed price, does generate higher prices than in the absence of reference pricing.

4.1.2 Average case: $\widetilde{p_r}_t = (1-\beta)\,\widetilde{p}_{1,t-1} + \beta\widetilde{p}_{2,t-1}$

When the reference pricing rule consists of the weighted average of firms' prices, proceeding in an equivalent way as in the previous sections, in the second stage firms' optimal pricing strategies are given by,

$$\begin{aligned} \widetilde{p}^*_{1,2} &= \frac{C}{5} + \frac{17}{35}q + \frac{2}{5}\widetilde{p_r} \\ \widetilde{p}^*_{2,2} &= \frac{C}{5} - \frac{3}{35}q + \frac{2}{5}\widetilde{p_r} \end{aligned} \tag{26}$$

with $\widetilde{p_r} = (1-\beta)\widetilde{p}_{1,1} + \beta\widetilde{p}_{2,1}$.

Plugging this optimum values on firms' PDV in the first stage and maximizing with respect to prices, the optimum at this stage is given by,

$$\begin{aligned} \widetilde{p}^*_{1,1} &= Aq + \widehat{p}^*_{1,1} \quad \text{with } A > 0 \\ \widetilde{p}^*_{2,1} &= Bq + \widehat{p}^*_{2,1} \quad \text{with } B < 0 \end{aligned} \tag{27}$$

with[9] $\widehat{p}^*_{i,1}$ being the equilibrium prices when there is no vertical differentiation. Hence, as we can observe from the above first stage equilibrium, while the branded firm will price higher when compared with the model without quality, the generic firm will price at a lower level ($\widetilde{p}^*_{1,1} > \widehat{p}^*_{1,1}$ and $\widetilde{p}^*_{2,1} < \widehat{p}^*_{2,1}$). Comparing the two firms ' pricing strategies, recall, from (25), that,

$$\begin{aligned} \frac{\widehat{p}^*_{1,1}}{\widehat{p}^*_{2,1}} - 1 &= \frac{84\delta\,(2\beta-1)}{48\delta\beta^2 - 132\delta\beta + 12\delta - 175} = L \\ &\Longrightarrow \; \widehat{p}^*_{1,1} = (L+1)\,\widehat{p}^*_{2,1} \end{aligned}$$

[9] With, $A = \frac{714\delta\beta - 1152\delta^2\beta^3 - 14875 + 1152\delta^2\beta^2 - 6120\delta + 1680\delta\beta^2}{35\left(240\delta\beta^2 + 144\delta - 240\delta\beta - 875\right)}$ and $B = \frac{2304\delta^2\beta^2 - 1152\delta^2\beta^3 + 1680\delta\beta^2 - 1152\delta^2\beta + 1260\delta\beta - 1860\delta + 2625}{35\left(240\delta\beta^2 + 144\delta - 240\delta\beta - 875\right)}$

For $\beta < 1/2$ $L > 0$ while for $\beta < 1/2$ $L > 0$. Using the above expression, the equilibrium prices defined on (27), can be written as,

$$\begin{aligned} \widetilde{p}_{1,1}^{*} &= Aq + \widehat{p}_{2,1}^{*}(1+L) \\ \widetilde{p}_{2,1}^{*} &= Bq + \widehat{p}_{2,1}^{*} \end{aligned}$$

Comparing the first period pricing strategies of the two firms,

$$\widetilde{p}_{1,1}^{*} - \widetilde{p}_{2,1}^{*} = q(A-B) + \widehat{p}_{2,1}^{*}L$$

Therefore the asymmetry between prices will depend on the reference price weight attached to firm' pricing strategies, β, and on the level of quality q. Indeed,

$$\text{For} \left\{ \begin{array}{lll} \beta < 1/2 & & \widetilde{p}_{1,1}^{*} > \widetilde{p}_{2,1}^{*} \\ \beta > 1/2 & \left\{ \begin{array}{l} \widetilde{p}_{1,1}^{*} > \widetilde{p}_{2,1}^{*} \\ \widetilde{p}_{1,1}^{*} < \widetilde{p}_{2,1}^{*} \end{array} \right. & \begin{array}{l} q > \frac{L}{B-A}\widehat{p}_{2,1}^{*} \\ q < \frac{L}{B-A}\widehat{p}_{2,1}^{*} \end{array} \end{array} \right.$$

On what concerns the reference price its level is given by,

$$\widetilde{p}_{r} = \widehat{p}_{r} + qI$$

Where $1 = f(\beta, \delta) = A(1-\beta) + \beta B$[10]. The sign of 1 depends on the value of β. Namely, for sufficiently low (high) values of β, $1 < 0$ ($1 > 0$). Contrarily to the previous scenario, now, given that both firms affect the reference price level, the impact of the pricing strategies is no longer necessarily (negatively) constrained by the degree of vertical differentiation. The role of quality on the level of the reference price will depend on the magnitude of β. If the banded firm plays a significant role on the determination of the reference price level, then the existence of product differentiation diminishes the reference price level. Indeed, for this firm $\widetilde{p}_{r}$ and q are substitutes in the sense of having similar impacts on demand and consequently on profits. Therefore, the higher the quality level the lower the scope, and consequently incentives, to increase profits via increased reference prices. That is, the incentive that this firm could have to increase first period prices is justified by increased demand via increased achieved by higher reference price levels. This incentive becomes smaller at higher levels of quality, with quality working as a substitute of reference pricing in terms of demand (and profits) effects. On the other hand, if the firm with a more determinant role on the level of the reference price is the generic firm, this incentive is increased, i.e., relatively to what happened to the other firm, there is now more scope for increased profits via higher reference prices.

Comparing with the equilibrium prices that would arise in the absence of reference pricing,

[10] With ,

$$I = \frac{2280\delta\beta + 3500\beta - 2975 - 1224\delta - 840\delta\beta^{2}}{35\left(240\delta\beta^{2} + 144\delta - 240\delta\beta - 875\right)}$$

$$\begin{aligned}\widetilde{p}_{1,1}^{*}-\widetilde{p}_{1,t,p_r=0}^{*} &= Eq+F>0 \quad \text{with } F>0 \\ \widetilde{p}_{2,1}^{*}-\widetilde{p}_{2,t,p_r=0}^{*} &= Gq+H>0 \quad \text{with } H>0\end{aligned} \tag{28}$$

For both firms, branded and generic, the price always exceeds the price in a set up without reference pricing[11]. Indeed, given that the introduction of reference pricing is equivalent to a positive increasing linear transformation in each firm profit function, the optimal price level is increased relatively to the scenario without reference pricing.

Decomposing the effect of reference pricing on firms profit stream,

$$\begin{aligned}\frac{\partial PDV_1}{\partial \widetilde{p_r}} &= \delta\frac{\partial p_{1,2}}{\partial \widetilde{p_r}}D_{1,2}+\delta\widetilde{p}_{1,2}\left[\frac{\partial D_{1,2}}{\partial \widetilde{p}_{1,2}}\frac{\partial \widetilde{p}_{1,2}}{\partial \widetilde{p_r}}+\frac{\partial D_{1,2}}{\partial \widetilde{p}_{2,2}}\frac{\partial \widetilde{p}_{2,2}}{\partial \widetilde{p_r}}+\frac{\partial D_{1,2}}{\partial \widetilde{p_r}}\right] \\ \frac{\partial PDV_2}{\partial \widetilde{p_r}} &= \delta\frac{\partial \widetilde{p}_{2,2}}{\partial \widetilde{p_r}}D_{2,2}+\delta\widetilde{p}_{2,2}\left[\frac{\partial D_{2,2}}{\partial \widetilde{p}_{2,2}}\frac{\partial \widetilde{p}_{2,2}}{\partial \widetilde{p_r}}+\frac{\partial D_{2,2}}{\partial \widetilde{p}_{1,2}}\frac{\partial \widetilde{p}_{1,2}}{\partial \widetilde{p_r}}+\frac{\partial D_{2,2}}{\partial \widetilde{p_r}}\right]\end{aligned}$$

we observe that an increase in the reference price level has two effects. First it increases prices in the last stage, indeed from (26) we can see that $\frac{\partial \widetilde{p}_{1,2}}{\partial \widetilde{p_r}}>0$. Even though this effect is the same for both firms, the total impact on profits of this effect on prices depends on the magnitude of the demand of each firm, that is a function of quality, reference and reservation prices and location variables. Firms' demand differs due to quality differentiation and, consequently, prices. The second effect stands for the impact of reference price on demand. This effect can be decomposed in two sub-effects: (a) the impact of reference pricing on demand via increased prices for both firms and (b) the direct effect of reference price on the demand. The total impact of these effects on firm's profits depends on the equilibrium prices that differ between firms due to differences in location and quality.

One interesting point for the analysis of firm's optimal pricing strategies is how these effects vary with quality. An increase in quality increases demand for firm 1 and decreases demand for firm 2. Hence it amplifies the first effect for firm 1 but decreases it for firm 2. Finally, because the amplitude of the remaining effects depends on the firm pricing strategies, an increase in quality

[11] With,

$$\begin{aligned}E &= \frac{-12\delta\left(714-96\delta\beta^2+96\delta\beta^3+200\beta^2-935\beta\right)}{35\left(-875+144\delta+240\delta\beta\left(\beta-1\right)\right)} \\ F &= \frac{84\delta C\left(5\beta-6\right)}{5\left(-875+144\delta+240\delta\beta\left(\beta-1\right)\right)}>0 \\ G &= \frac{-12\delta\left(119+96\delta\beta\left(\beta-1\right)^2-200\beta^2-45\beta\right)}{35\left(-875+144\delta+240\delta\beta\left(\beta-1\right)\right)} \\ H &= -\frac{84C\delta\left(5\beta+1\right)}{5\left(-875+144\delta+240\delta\beta\left(\beta-1\right)\right)}>0\end{aligned}$$

increases the price charged by firm 1 while it decreases the price charged by firm 2. Therefore, given that $\frac{\partial D_{1,2}}{\partial \widetilde{p}_{1,2}} \frac{\partial \widetilde{p}_{1,2}}{\partial \widetilde{p_r}} + \frac{\partial D_{1,2}}{\partial \widetilde{p}_{2,2}} \frac{\partial \widetilde{p}_{2,2}}{\partial \widetilde{p_r}} + \frac{\partial D_{1,2}}{\partial \widetilde{p_r}} > 0$, an increase in quality amplifies the positive total effect of reference price on demand. For firm 2, given that $\frac{\partial D_{2,2}}{\partial \widetilde{p}_{2,2}} \frac{\partial \widetilde{p}_{2,2}}{\partial \widetilde{p_r}} + \frac{\partial D_{2,2}}{\partial \widetilde{p}_{1,2}} \frac{\partial \widetilde{p}_{1,2}}{\partial \widetilde{p_r}} + \frac{\partial D_{2,2}}{\partial \widetilde{p_r}} > 0$ and $\frac{\partial \widetilde{p}_{2,2}}{\partial q} < 0$ an increase in quality diminishes the positive impact of reference pricing on profits. Hence, depending on the magnitude of the effects described above, the overall effect of the introduction of reference price depends not only on the reference price itself but also on the quality level.

Going one step further, the role of quality on the impact of reference price on firms' optimal pricing strategies depends on the reference price formulation, namely on the parameter β. The two polar cases arise when $\beta = 0$ and $\beta = 1$, with the former being equivalent to the previously analyzed min case while the latter to a scenario where the reference price is given by the highest drug price in the market. For $\beta = 1$, the gap between prices with and without reference pricing decreases with quality. With quality differentiation the increase in prices due to the implementation of the reference price policy is reduced, mirroring the results found in the previous section. Intuitively, as $\beta \to 1$ the "reference price setter" is firm 2, with firm 1 pricing strategies playing no role in the determination of the reference price level. In order to increase reference price, and consequently profits, firm 2 has to price at higher levels. Nevertheless, due to vertical differentiation, its ability to profitably raise its price is limited. Given that this hurdle arises on the market power conferred to firm 1 due to product differentiation, it is exarcebated by an increase in quality. For $\beta = 0$, the existence of quality differentiation strengthens the positive effect on prices after the introduction of reference pricing. If in the set up without quality firms would price higher than without reference pricing, in this set up this effect is even higher due to quality. Given that the reference price setter is now the firm with quality advantage, the competition pressure is now weaker allowing higher prices. In a sense, increasing the price of a drug will have two effects: income and substitution effect. The firm that increases its price will, *ceteris paribus*, face less demand today due to consumers that switch to the competitor drug but will see its demand increased next period due to an income effect. While the income effect affects equally both firms, the substitution effect is stronger for firm 1. Moreover the higher the degree of vertical differentiation the higher the negative impact on firm's j demand due to the substitution effect. Therefore, if this firm is the reference price setter, the (positive) impact of reference price on market prices is weaker.

5 Discussion

With the above exposition we have concluded that the introduction of reference pricing does lead to higher prices. Without wanting to go deeper into the formalization of the mechanism by which it happens, we would like though to further comment it. Firms pricing behavior can be attributed to two factors. The first concerns the formulation of the reference price level, namely the fact that it is built upon firms pricing strategies and consequently is endogenous to firms actions. The crucial fact that makes this endogeneity relevant is an "anticipation factor", i.e., the fact that each period reference price level is a function of the previous period pricing strategies. This is what allows firms to, in the first period, revise their pricing strategies adapting to the new institutional environment and consequently jeopardizing the envisioned goals of the policy.

If this was the only factor behind pricing behavior it would be easy to tackle. Nevertheless, there is a second factor that facilitates higher pricing behavior that is the fact that reference price works as a lower bound on pricing strategies that allows firms to set higher prices. This effect can be easily isolated by analyzing the equilibrium pricing strategies in a set up with reference pricing but where one period prices does not affect other periods profits. Indeed, computing the Nash Equilibrium of such one shot game, the optimal pricing strategies is characterized by,

$$p_1 = p_2 = \frac{\Delta + 2k + 2p_r}{5}$$

As we can observe from the equilibria described above and comparing it with firms' pricing strategies in the absence of reference pricing , with the introduction of this policy, firms price at higher levels, indeed, under both scenarios we have that the equilibria is characterized by prices above the optimal level in the absence of reference pricing. More crucially, we find that, for some parameter configurations, the reference pricing level works as a lower bound on firms' optimal pricing strategies.

Finally by analyzing first period pricing strategies, we observe that even though the reference pricing policy has not yet been introduced, firms do increase prices in order to experience higher profits in the coming periods, fact that is consistent with the "anticipation factor" described above.

6 Conclusions

Within a horizontally differentiation model, we analyze the effects of reference pricing reimbursement on firms' pricing strategies. With this analysis we find inherent incentives for firms' pricing behavior, and consequently we shed some light on time consistency of such policy.

In a first instance we consider a market served by two identical firms that compete in prices in a two stage non cooperative game, having that a reference pricing policy is announced in the beginning of the first period to be introduced after firms having decided on optimal strategies in the first stage but before they compete in the second stage

Finally, within the same set-up we allow for quality differences in order to capture competition between generic and branded drugs. The same analysis is developed but this time with one firm providing (exogenously) some quality while the other no quality.

In both set ups we study two particular reference price rules. Namely, the first analyzed is one where the reference price level in any period is given by the minimum observed price in the previous period. The second rule consists of setting the reference price level in any period as the weighed average of firms' prices in the previous period.

We find that the introduction of reference pricing policy in a scenario without vertical differentiation may lead to higher, rather than lower, prices. This is always true after the introduction of reference pricing as, for any reference pricing rule, the observed prices are consistently higher than in the absence of regulation. Thus, the original envisaged aim of the policy is completely jeopardized.

Also, due to the fact that firms correctly anticipate that the forthcoming reference pricing is, in fact, computed based on their own present pricing strategies, they immediately realize that they can affect its level, and, therefore, increase their future demand.

In particular, while the "minimum policy" would imply that the firms are not able to coordinate on higher prices like they would in the absence of reference price, on the contrary, the "linear policy" implicitly provides a coordination device. In fact, in such a case the equilibrium pricing behavior in the period before the introduction of reference pricing is such that both firms sustain higher prices than in the absence of regulation. Therefore, if the regulator deals with a symmetric market, in order to avoid higher prices, he should implement a policy where the reference pricing consists of the minimum observed price.

When there is vertical differentiation the results are somehow different. This case is particularly interesting as by allowing for different (perceived) qualities it better describes a reality where both branded and generic drugs are sold in the market.

If quality differentiation is introduced in the market, not only the pricing behavior in the last period leads to higher prices than in the absence of regulation for both firms (although their pricing strategies are asymmetric), but, more crucially, both the minimum and linear policies unambiguously imply higher prices also in the first period.

Within a horizontally differentiation model, we analyze the effects of reference pricing reimbursement on firms' pricing strategies. With this analysis we find inherent incentives for non-cooperative pricing behavior between firms, and consequently we shed some light on time consistency of such policy.

References

[1] Danzon, PM. and H Liu. Reference Pricing and Physician Drug Budgets: The German Experience in Controlling Pharmaceutical Expenditures", Wharton School, Working Papers Series, 1996

[2] Danzon, P. and Li-wei Chao. Does regulation Drive out Competition in the Pharmaceutical Industry?, Journal of Law and Economics 2000; 43(2)

[3] Economides, N. The principle of Minimum Differentiation Revisited, European Economic Review 1986; 24; 345-368

[4] Hotelling, H. Stability in Competition, Economic Journal 1929; 39; 41-57

[5] Lopez-Casasnovas, G., Jonsson, B. Reference Pricing and Pharmaceutical Policy. Springer: Barcelona; 2001

[6] Ma, AC. Health care payment systems: cost and quality incentives. Journal of Economics and Management Strategy; 1994; 3(1); 93-112

[7] Merino-Castelló, A. Impact of the Reference Pricing System on the Pharmaceutical Market: A Theoretical Approach.Universitat Pompeu Fabra, Working Paper Series; 2003; Working Paper 524a

[8] Mestre-Ferrandiz, J. Reference prices: The Spanish Way, IAE Working Paper 481.01, Universitat Autonoma de Barcelona 2001

[9] Morton, FS. Entry decisions in the generic pharmaceutical industry. Rand Journal of Economics. 1999; vol. 30, no. 3, pages 421-440

[10] Mossialos, E. and J. Le Grand. Health Care and Cost Containment in the European Union. Aldeshot , Brookfield, USA : Ashgate 2002

[11] Mossialos, E., (2002), "Funding health care : options for Europe", Buckingham : Open University Press, European Observatory on Health Care Systems series